Implementation of Smart Operation Strategies for Air-Conditioning and Lighting Systems for Ministries Complex in the State of Kuwait

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ABSTRACT

The smart operation strategies were implemented for Air-Conditioning (A/C) and lighting systems to reduce the national load at Ministries Complex (MC) in the state of Kuwait. The A/C system in MC is a district cooling system that comprises of 8 chillers with water-cooled condensers and four circuits of chilled water distribution with their independent pumps feeding to 184 air-handling units (AHUs), including 26 independent fresh air units. Total connected load of A/C systems is 8,867 kW, while fan motors of AHUs account for 2,390 kW. Lighting system in MC comprises mostly of energy efficient T12 fluorescent tubes and compact fluorescent lamps with a total connected load of 2,254 kW.

Pre Closing Treatment (PCT) between 13:00 and 14:00 h, when the building was still occupied, was explored. Fresh-air AHUs were closed at 13:00 h instead of 14:30. Also, Time-of-Day Control (TDC) for AHUs and lighting systems along with the cooling production and cooling distribution systems was applied between 14:00 and 15:30 h, inline with the building occupancy for each building at MC. PCT and TDC schemes for chillers, AHUs and lighting systems were carried out through the Building Automation System (BAS).

Implementation of the smart operation strategies for A/C and lighting systems was successful at MC. The temperature build up did not exceed 1°C during PCT scheme and the temperature did not exceed 28°C during TDC scheme. The savings in peak load demand were 610 kW between 13:00 and 14:00 h, 4,500 kW between 14:00 and 15:00 h, and 6,897 after 15:30 h. The reduction of 4,500 kW at 15:00 h is equivalent to $7.6 million towards constructing power plant and distribution network. Savings of 13,720 kWh in daily energy consumption was achieved due the implementation of the smart operation strategies. These savings led to a reduction of $1,500 per typical summer day of the MEW fuel bill and 8,918 kg/day of CO_2 emissions. To make MC building more energy efficient, it is recommended to retrofit AHUs and secondary chilled water pumps with variable frequency drives (VFDs).

Key words: Peak Load, Air-Conditioning, Pre Closing Treatment, Time-of-Day Control,

INTRODUCTION

National load management is important for any utility to ensure un-interrupted electricity supply at optimum cost. This is achieved by restricting the demand for electrical power by consumers and improving the load patterns to enhance the national load factor.

The Ministry of Electricity and Water (MEW), the sole utility in the State of Kuwait, spends over $3.45 billion every year to meet the entire electricity requirements of the country. The majority of electricity is consumed by buildings, leading to high greenhouse gas emissions. Therefore, implementation of energy efficiency and energy conservation programs in buildings is very important to minimize the demand for both power and energy in Kuwait.

Kuwait Institute for Scientific Research (KISR) has developed, implemented, validated and improved a wide range of solutions to manage power and energy in buildings. These solutions ensure uncompromising comfort quality with minimum power and energy demand. Energy Conservation Code of Practice, developed by KISR and implemented by MEW since 1983 for all types of A/C buildings, has been a remarkable success (MEW, 1983). Without this code, the country would have needed 3,000 MW of additional power generation capacity. The accumulative savings due to the code are estimated to be well over $10.4 billion (Meerza and Maheshwari, 2002). A revised code had been already in effect sine the beginning of 2009, which further enhances the energy efficiency in buildings (MEW, 2009). Energy Auditing**,** the first step towards a comprehensive energy management plan in existing buildings, has been carried out in a number of major buildings since 1995, leading to reductions in annual energy consumptions of well over 20% (Maheshwari et al, 1997; Al-Ragom et al, 2002; Al-Ragom et al, 2005; Hajiah et al, 2007).

To reduce the national peak load demand in the nation, KISR suggested implementing the smart operation strategies of A/C and lighting systems in a number of large governmental and institutional buildings to MEW during the summer of 2007 since most of these buildings are operated from 7:30 to 14:00 h. Therefore, the load of these buildings can be reduced drastically after 14:00 h to help minimizing the national peak load demand which occurs between 12:00 and 17:00 h. MEW accepted the idea and consequently a number of governmental and institutional buildings were selected to implement the smart operation strategies. One of these buildings was Ministries Complex (MC) building located in Mirqab, Kuwait City.

This paper gives details of load distribution, A/C and lighting details, specifications of the building automation systems (BAS) and operation schedules. Also, the paper illustrates the development of the smart operation strategies and achieved savings in peak load demand and energy consumption.

BUILDINGS DESCRIPTION

MC, commissioned in 1981, consists of twelve identical buildings for ministries, two buildings for VIPs and four interconnecting areas, as illustrated in Fig. 1. It has 7,500 employees and an average of 9,000 daily visitors. Building occupancy begins at 7:30 h and ends between 14:00 and 15:30 h as shown in Table 1. A/C and lighting systems are the major power users in MC and in addition to other miscellaneous users. The types of construction and glazing are pre-cast blocks with no insulation and single-plain, respectively. The total A/C area is 150,000 m^2.

Fig. 1. Picture of Ministries Complex.

Table 1. Occupancy Schedules for each building at MC.

Building number	Type	Work Time (h)	
		Start	**End**
1	Typical	7:30	14:00
2	Typical	7:30	14:00
3	Typical	7:30	15:00
4	Typical	7:30	14:30
5	Typical	7:30	14:00
6	Typical	7:30	14:00
7	VIP	7:30	15:00
8	Interconnecting	-	-
9	Interconnecting	-	-
10	Interconnecting	-	-
11	Typical	7:30	14:30
12	Typical	7:30	14:30
13	Typical	7:30	14:30
14	Typical	7:30	14:00
15	Typical	7:30	14:00
16	Typical	7:30	14:00
17	VIP	7:30	14:00
18	Interconnecting	-	-

Air-Conditioning system

The HVAC system consists of 9 chillers with one standby chiller, water-cooled condenser and centrifugal compressors, primary and secondary chiller water pumps, condenser water pumps and cooling towers. The schematic of the cooling production at MC is illustrated in Fig. 2. Chillers are divided in two groups each with four chillers connected in parallel; each chiller has a nominal cooling capacity of 990 RT and connected load, a nominal of 860 kW each. Four chillers located upstream (Group A) are designed to reduce temperature of chilled water from 14 to 9^{o}C. While the other four chillers located down stream (Group B) are designed to reduce the chilled water temperature from 9 to 5^{o}C. Cooling system is constant chilled water flow system with a designed flow rate of 11,800 GPM. Table 2 shows the connected load for different parameters of chillers and their auxiliaries.

For the circulation of chilled water there are primary and secondary chilled water pumps and their connected loads are listed in Table 2. Four primary chilled water pumps along with an additional standby pump. Secondary chilled water pump have four flow circuits, each circuit having two pumps in operation and one as standby. The secondary chilled water pumps circulate chilled water from chillers to feed each and every AHU and Fan Cooling Unit (FCU) in 18 buildings.

Water is utilized in water-cooled chillers as a medium for the absorption of heat rejection from the condenser. The connected loads for the condenser water pumps and cooling tower fans are illustrated in Table 2. Six ceramic cooling towers with enhanced airflow by change of fan pitch are retrofitted with VFD’s. The designed inlet and outlet water temperatures for the cooling towers are 33.3°C (92°F) and 27.2°C (81°F), respectively.

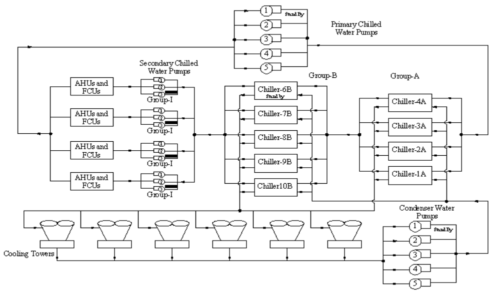

Figure 2. Schematic of the cooling production at the Ministries Complex.

Table 2. Connected loads for chillers and their auxiliaries.

Component Name	Quantity	Unit Load (kW / unit)	Total Load (kW)
Chillers	8+1	860	6,880
Primary Pumps.	4+1	93.3	373.2
Secondary Pumps.			
Circuit I	2+1	149	298
Circuit II	2+1	45	90
Circuit III	2+1	75	150
Circuit IV	2+1	75	150
Condenser Pumps.	4+1	149	596
Cooling Tower Fans	6	55	330
Total			**8,867**

Air Distribution System

MC are divided into three groups of 12 identical ministries, 2 VIP and 4 circulation area buildings where the AHUs are identical in each building group. Each ministry building is having 8 AHUs and 2 fresh air AHUs. VIP building has 7 AHUs and 1 fresh air AHU and the circulation area consists of 12 AHUs. Table 3 shows the total number and loads of AHUs in MC. The total connected load of the AHUs is approximately 2,390 kW. All AHUs are 3-way modulated valves and constant-air-volume (CV) with inlet-guide vans (IGV) type. The supply air temperature at the AHU is controlled by the Building Automation System (BAS), however the amount of air supplied (CFM) to the space is controlled by Modoline which is being adjusted manually. In addition, there are additional 48 FCUs which supply cooling loads to the shops and banks in the ground level at MC. The total connected load for these FCUs is approximately 58 kW.

Table 3. Connected loads for AHUs

Component	Quantity	Total Load (kW)
AHUs	158	1,987
Fresh Air AHUs	26	403
Total		**2,390**

Lighting systems

Lighting in MC is the second major consumer of electricity. A number of different types of lights are used in MC which includes fluorescent and compact fluorescent lamps and incandescent lamps such as halogen and parabolic aluminum reflector (PAR) lamps. The fluorescent lamps used are old T12 tubes of 20 W and 65 W, while the CFLs used are around 15 W. As for the PAR lamps, they are of 80 W and the halogens are of 35 W.

In MC lighting system is distributed into four zones on each floor with separate distribution boards (DBs) feeding each zone separately, the lights can be controlled manually as well as automatically through BAS. For the automatic control of lighting DBs are utilized as these DBs are connected to BAS. For the manual control there are two switches on each floor that control the lighting for the entire floor. Table 4 gives the summary of total connected load for all buildings. The total connected lighting load for MC is estimated to be 2,254 kW

Table 4. Total Lighting Load of Ministries Complex.

Building Type	Lighting Load (kW)	Number of Buildings	Total Load (kW)
Identical Buildings	161	12	1,932
VIP Buildings	113	2	226
Circulation Areas	24	4	96
Total			**2,254**

Additional Loads

Apart from HVAC, air distribution systems and lighting there are a number of additional loads that adds to a considerable percentage of total loads in the complex. Additional load in MC includes elevators, escalators, supply and extract fans, fans for staircase and lavatories etc. MC has a total of 38 elevators and 16 escalators with a total connected load of 1,906 kW. The elevators have variable voltage variable frequency drives (VVFD) dedicated for energy savings. Table 5 gives the breakdown of these loads.

Table 5. Additional load at MC Building

Component	Quantity	Unit load (kW / unit)	Total load (kW)
Elevators	36	38	1,368
	2	45	90
Escalators	8	32	156
	8	24	192
Staircase fans	25	3	75
Lavatory fans	21	0.75	15.75
Parking Supply fans	16	35	560
	4	20	80
parking Extract fans	27	48	1,296
Elevator fans	12	0.75	9
Total			**3,942**

Features of Building Automation Systems (BAS)

The BAS at MC can control on/off operations of lighting systems and AHUs. Duct pressure and supply air temperature are controlled through BAS. However, air space temperature is not controlled through BAS. The operations of chillers and their auxiliaries can also be controlled through BAS.

Operation Schedules

The operation schedules of the A/C system is divided into 3 seasons (winter, intermediate and summer) controlled by the ambient temperature which automatically set the chilled water supply to different AHUs and FCUs for all buildings at MC. Table 6 gives the designed chilled water supply for each season. Additionally, AHUs are also switched on/off during the day, however the time schedules is different depending on the season and set supply air temperature. Table 7 gives the supply air temperature and operation-time schedules of the plant room and AHUs for different seasons. During the summer season, plant room including the chillers and AHUs start at 03:00 h and switched off at 19:00 h. Fresh air AHUs starts at 6:30 am and switched off at 14:30 pm throughout the year. However, fresh air AHUs are switched off during high humidity weather to reduce the load on the chillers since the chillers are water-cooled condensers and the efficiency of cooling towers reduces during high humidity climatic conditions. It was noted that no more than 6 chillers are in operations during peak summer season with high humidity, but 5 chillers are only in operations during low humidity. Lighting schedule at MC is the same for all the buildings, the operation of lighting systems are between 05:00 and 17:00 h.

Table 6. Supply water temperature for different seasons.

Ambient Temperature (°C)	Season	Chilled water (°C)
Ta < 25	Winter	9
25 < Ta < 35	Intermediate	7
Ta > 35	Summer	5

Table 7. Supply air temperature and time schedule for plant room and AHUs at MC.

Ambient Temperature (°C)	Supply air Temperature (°C)	Open Time (h)	Closure Time (h)
Ta < 25	18	06:00	16:00
25 < Ta < 35	15	04:00	17:00
Ta > 35	13	03:00	19:00

APPROACH AND METHODOLOGY

The smart operation strategies were implemented only for A/C and lighting systems. These strategies were developed and finalized in consultation with the facility manager and their technical team. Prior to the development of the smart operation for MC, critical areas were identified in consultation with the facility manager. Critical areas are the zones in the building where the comfort quality, particularly the space temperature, has to be maintained at constant level for most of the day. This requirement could be either due to their occupants, such as ministers and other top executives.

Pre Closing Treatment (PCT) between 13:00 and 14:00 h, when the building was still occupied, was explored. Fresh-air AHUs were closed at 13:00 h instead of 14:30. Also, Time-of-Day Control (TDC) for AHUs and lighting systems along with the cooling production and cooling distribution systems was applied between 14:00 and 15:30 h, inline with the building occupancy for each building at MC. PCT and TDC schemes for chillers, AHUs and lighting systems were carried out through BAS.

Modifications in Operation schedules

After detailed analysis of each building at MC, operation schedules for chillers and their auxiliaries, AHUs, and lighting systems were modified as follows:

1. Start the operations of the chillers, their auxiliaries and AHUs in all typical ministries buildings (1-6 and 11-16) and VIP buildings (7 and 17) at 01:00 a.m.
2. Open Fresh Air AHUs in all typical ministries buildings (1-6 and 11-16) and VIP buildings (7 and 17) at 06:30 h and close them at 13:00 h.
3. Open all A/C units in circulations area buildings (8, 9, 10, 18) at 5:30 am. and close them at 13:00.
4. Start the operations of lighting system by 6:00 am in all typical, VIP and circulation area buildings.
5. Stop time of AHUs and lighting system was related to the end time of work at each building.
6. Complete closure of the plant room follows after the closure of last AHUs at 15:00 at buildings 3, 7 and 17.

However, complains started to come from different buildings leading to modification in the operation schedules for chillers and their auxiliaries and AHUs. Changes were as follows:

1. Start the operations of the chillers, their auxiliaries and AHUs in all typical ministries buildings (1-6 and 11-16) and VIP buildings (7 and 17) at 00:00 a.m.
2. Open Fresh Air AHUs in all typical ministries buildings (1-6 and 11-16) and VIP buildings (7 and 17) at 03:00 h and close them at 13:00 h.
3. Change the closure time of AHUs and lighting system for VIP buildings (3,7 and 17) to 15:30.

Table 8 summarizes the operation schedules of the chillers, their auxiliaries and fresh air AHUs, AHUs and lighting systems before implementation and after 1st and 2nd implementations.

RESULTS AND DISCUSSION

The implementation of the smart operation strategies for A/C and lighting systems were successful. Direct and indirect savings of 610 kW at 13:00 h was achieved due to closure of fresh air AHUs in all buildings (363 kW), AHUs in interconnecting areas (107 kW) and lighting in interconnecting areas (112 kW). Direct and indirect savings of 4,500 kW between 14:00 and 15:00 h was

Table 8. Operation schedules of chillers and their auxiliaries, fresh air AHUs, AHUs and lighting systems before and after implementation

Component	Before Imp. (h)	After 1st Imp. (h)	After 2nd Imp. (h)
Chillers	3:00-19:00	1:00-15:00	00:00-15:30
Auxiliaries	3:00-19:00	1:00-15:00	00:00-15:30
Fresh Air	6:30-14:30	6:30-13:00	0300-13:00
AHUs	3:00-19:00	1:00-14:00 to 15:00	0:00-14:00 to 15:30
Lighting	5:00-17:30	6:00- 13:00 to 15:30	6:00-13:00 to 15:30

achieved because of the closure of additional AHUs (1,030 kW) and lighting system (1,180 kW) in some ministries buildings. Direct and indirect savings of 6,897 kW after 15:30 was achieved by complete closure of the remaining AHUs (310 kW), lighting (470 kW), and complete closure of chillers and their auxiliaries. Overall reduction in MC power demand was over 5% between 13:00 h and 14:00 h, in the range of 40 to 55% between 14:00 and 15:30 h and around 70% after 15:30 h. The hourly savings in load demand and their percentages between 13:00 and 20:00 h is illustrated in Fig. 3. The critical hour in the national load is at 15:00 h. Load at MC was reduced by 4,500 kW at that hour which is equivalent to savings of KD. $7.6 million towards constructing power generation and distribution costs (based on $1.66 million for 1 MW of peak load saved).

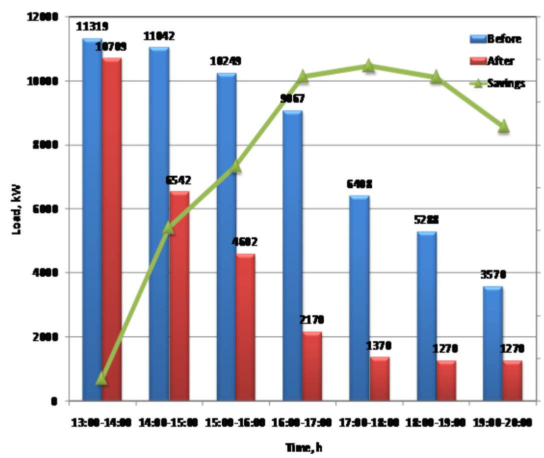

Figure 3. Load before and after Implementation with Savings.

The temperature build up did not exceed 1°C during PCT scheme between 13:00 and 14:00 and the temperature did not exceed 28°C during TDC scheme at MC. These temperature values confirmed successful implementation of the smart operation strategies.

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The implementation of the smart operation strategies had also led to a saving in daily energy consumption. The measured energy consumption was 171,689 kWh before implementation and was reduced to 157,969 kWh after implementing these smart strategies. The saving of 13,720 kWh led to a reduction of $1,500 per typical summer day of the MEW fuel bill (based on $60 per barrel of oil) and 8,918 kg/day of CO_2 emissions (based on 1 kWh of power generation releases 0.65 kg of CO2 emissions).

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations of the implementation of the smart operation strategies in MC building can be summarized as follows:

1. Implementation of the smart operation strategies for A/C and lighting systems was successful. The temperature build up did not exceed 1^oC during PCT scheme and the temperature did not exceed 28^oC during TDC scheme.
2. The savings in peak load demand were 610 kW between 13:00 and 14:00 h, 4,500 kW between 14:00 and 15:00 h, and 6,897 after 15:30 h.
3. The reduction of 4,500 kW at 15:00 h is equivalent to $7.6 million towards constructing power plant and distribution network.
4. Savings of 13,720 kWh in daily energy consumption was achieved due the implementation of the smart operation strategies. These savings led to a reduction of $1,500 per typical summer day of the MEW fuel bill and 8,918 kg/day of CO_2 emissions.
5. To make MC building more energy efficient, it is recommended to retrofit AHUs and secondary chilled water pumps with variable frequency drives.

ACKNOWLEDGMENT

The authors would like to acknowledge the Ministry of Electricity and Water – Kuwait, for funding this project (EU046C) and Ministry of Finance – Kuwait for allowing KISR/MEW team to implement the smart operation strategies in MC building.

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